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Structure and Stimulus Familiarity: A Study of Memory in Chess-Players with Functional Magnetic Resonance Imaging

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A grandmaster and an international chess master were compared with a group of novices in a memory task with chess and non-chess stimuli, varying the structure and familiarity of the stimuli, while functional magnetic resonance images were acquired. The pattern of brain activity in the masters was different from that of the novices. Masters showed no differences in brain activity when different degrees of structure and familiarity where compared; however, novices did show differences in brain activity in such contrasts. The most important differences were found in the contrast of stimulus familiarity with chess positions. In this contrast, there was an extended brain activity in bilateral frontal areas such as the anterior cingulate and the superior, middle, and inferior frontal gyri; furthermore, posterior areas, such as posterior cingulate and cerebellum, showed great bilateral activation. These results strengthen the hypothesis that when performing a domain-specific task, experts activate different brain systems from that of novices. The use of the experts-versus-novices paradigm in brain imaging contributes towards the search for brain systems involved in cognitive processes.
Keywords: memory, fMRI, expertise, stimulus

Un gran maestro y un maestro internacional de ajedrez se compararon con un grupo de aficionados en una tarea de memoria con estímulos ajedrecísticos y no ajedrecísticos, variando la estructura y familiaridad de los estímulos, mientras se tomaron imágenes cerebrales usando resonancia magnética funcional. El patrón de activación cerebral difirió entre los maestros y los aficionados. Los maestros no presentaron ninguna diferencia en activación cerebral cuando se compararon distintos niveles de familiaridad y estructura de los estímulos; en cambio, los aficionados presentaron diferencias en activación cerebral en dichas comparaciones. Las diferencias más considerables se encontraron en el contraste de familiaridad del estímulo en posiciones de ajedrez. En ese contraste hubo una extensa actividad cerebral bilateral en regiones frontales como la corteza cingulada anterior y los giros frontales superior, medio e inferior; asimismo, áreas posteriores como la corteza cingulada posterior y el cerebelo también mostraron gran activación bilateral. Estos resultados fortalecen la hipótesis de que cuando los expertos realizan tareas específicas de dominio activan sistemas cerebrales diferentes a los que usan los aficionados ejecutando la misma tarea. El uso del paradigma expertos-versus- novatos en imaginería cerebral contribuye a la búsqueda de sistemas cerebrales involucrados en procesos cognoscitivos.
Palabras clave: memoria, resonancia magnética funcional, pericia, estímulo

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This article presents a study of memory using functional magnetic resonance imaging (fMRI) in chess-players. There is an extensive tradition of research in psychology using chess-players as research subjects to study cognitive processes such as perception (i.e., Chase & Simon, 1973b; De Groot & Gobet, 1996), memory (i.e., Charness, 1976; Chase & Simon, 1973a; Gobet & Simon, 1996b), thinking (i.e., De Groot 1946/1978; Gobet, 1998), and visual imagination (Campitelli & Gobet, 2005; Saariluoma & Kalakoski, 1997).

Chess has been chosen as a task environment for psychological research for the following reasons. First, the laboratory experiments with chess-players are an ideal compromise between internal controllability and ecological validity. In turn, the chess board with chess pieces is a very simple environment (therefore, controllable), in which an immense number of possibilities can be generated (2^{143}, see De Groot & Gobet, 1996). Therefore, it is an ecologically valid task environment with high controllability and freedom to manipulate many variables (Gobet & Simon, 2000). Another important reason to use chess in the laboratory is the existence of an international ranking (Elo, 1978) that allows the correct establishment of levels of excellence and makes it possible to compare different experiments. Lastly, the databases of chess masters' games are easily accessible, which contributes flexibility to generate stimuli. Therefore, the use of chess-players and chess tasks is an important tool for the study of cognitive processes. In this article, we focus on memory and its neural bases.

Two theoretically relevant phenomena were discovered in memory research using chess-players as subjects: Their performance was poorer in memory tasks when the logical structure of the specific stimulus of the domain of excellence was modified, and they maintained their level of performance in memory tasks when less familiar symbols were used to represent the position (i.e., the use of the initial of the name of the chess piece on the board, instead of the normal symbol that represents the piece).

The deterioration of their performance due to presentation of a modified stimulus structure was corroborated in many experiments using reconstruction of chess positions. De Groot (1946/1978) presented chess positions for a 2-15 s time lapse to chess-players of various levels. After presenting the position, it was withdrawn and participants were asked to reconstruct it. Recall performance was a function of the chess-players' level, with the grand masters achieving scores of almost 100% of the pieces placed in the correct position. Chase and Simon (1973b, 1973a) obtained the same result, introducing a new condition. In this condition, the task was the same, but the distribution of the pieces on the board was random, that is, the logical structure of a chess position was modified. In this condition, the masters' performance was almost as poor as the novices'. This result was corroborated in numerous studies. Gobet and Simon (1996a) performed a meta-analysis and found that, although the difference in performance between masters and novices was minimal, there was a significant difference favoring the former.

Gobet and Simon (1996b, 2000) presented the templates theory—an extension of the chunks theory (Chase & Simon, 1973b)—to explain the above-mentioned phenomenon. The templates theory maintains that, throughout their careers, chess-players learn chunks (segments of information) of typical chess configurations which are stored in long-term memory. With practice and study, some of these chunks of 3 or 4 pieces are transformed into templates of 10 or 12 pieces. These configurations make up the core of the template that can be completed by additional information. This long-term structure is automatically activated when chess-players perceive a chess position. The more experience a chess-player has, the more templates stored in long-term memory; hence, the greater quantity of positions that could be automatically recognized and, therefore, performance in recall and recognition tasks would be better. However, in random positions, as the logical structure of a chess position has been modified, there are very few recognizable configurations, leading to a poorer performance.

The templates theory was implemented in a computer model—CHREST (Gobet & Jansen, 1994)—that contains a "mental eye," a short-term memory, and a long-term memory. The mental eye allows the formation of mental images, either from retina stimulation or from the activation of information in memory. The short-term memory is a vector with a capacity for 4 items, and the long-term memory contains a discrimination network in which chunks and templates are formed by means of familiarization and discrimination processes. This model has successfully simulated the performance of chess-players of different levels in memory tasks (Gobet & Simon, 2000), as well as the chess-players' eye-movements (De Groot & Gobet, 1996). It has also simulated problem-solving in computer programmers (Lane, Cheng, & Gobet, 2001) and language acquisition (Gobet et al., 2001).

The phenomenon of maintaining the level of performance when the symbols that represent the chess pieces are modified was also discovered by Chase and Simon (1973). These authors replaced the chess pieces with the initials of the pieces and observed that performance in the aforementioned memory task was not affected. Saariluoma (1991) and Saariluoma and Kalakoski (1997), using a different task, substituted the pieces with black dots and obtained no variation in memory performance.

Taking into account the two phenomena analyzed, we designed an experiment in which the structure variables (logical positions vs. random positions) and familiarity (chess symbols on a chess board vs. geometrical figures on a grey-and-white board) were manipulated and we used the fMRI technique to explore which brain areas were activated in chess masters and novices. We chose a simple memory task so that the differences in brain activation would not be related to differences in performance.

Previous studies using neuroimages with chess-players have investigated various cognitive processes. Nichelli and colleagues (1994) found brain activation in the left middle temporal lobe in a task that consisted of determining whether or not a move was legal. Onofrj et al. (1995) and Atherton, Zhuang, Bart, Hu, and Sheng (2003) studied chess-players who had to solve a chess problem while their brain activity was recorded. Onofrj et al. found brain activity in the nondominant superior frontal lobe and medial temporal lobe (that is, the right hemisphere in right-handed individuals and the left one in left-handed individuals). Atherton et al. found left hemisphere activation in the superior frontal lobe and cerebellum, and bilateral activation in the precuneus and posterior cingulate cortex. Lastly, Amizdic, Riehle, Fehr, Wienbruch, and Elbert, (2001) obtained brain images of chess-players while they played a game against a computer. They found a different distribution of brain activation in masters as compared with players of a lower level. The former showed a relatively more extended activation pattern in the frontal and parietal lobes than in medial temporal areas, whereas the lower level chess-players showed a relatively opposite distribution.

Summing up, the previous studies showed that the tasks requiring a greater cognitive demand, such as solving a chess problem or playing a game of chess, tend to activate frontal and parietal areas (Amizdic et al., 2001; Atherton et al., 2003; Onofrj et al., 1995). Conversely, tasks that require the mere retrieval of relevant information, such as chess rules, tend to activate temporal areas (Nichelli et al., 1994). This is in accordance with prior studies that showed that the frontal and parietal lobes participate in maintenance and manipulation of information or in “executive” tasks, and the temporal lobes participate in long-term storage of memories (see Cabeza & Nyberg, 2000, for a review of studies of brain imaging).

We proposed a series of hypotheses concerning the structure and familiarity of the stimuli presented in each condition. We considered the possibility that novices would be less familiar with the chess pieces than with geometric figures. Hence, the differences in familiarity should be reflected in brain activation, showing more activation in areas of maintenance and manipulation of information (especially frontal areas) for the conditions with chess pieces. However, differences in structure should not affect them, as they have no chess experience that would lead them to differentiate logical positions from random positions.

In the case of masters, taking into account the scientific literature, we believe that as long as there is the possibility of associating a geometric figure with a chess piece (and we ensured this occurrence by using figures that were similar to the typical symbols used in chess notations and by requesting the players to go over the identity of the figure with the pieces), they would not be affected by the differences in familiarity because the figures presented would refer to chess pieces (see Chase & Simon, 1973b; Saariluoma 1991, Saariluoma & Kalakoski, 1997). In contrast, given the extensive literature reporting differences in memory task performance between logical and random positions (see Gobet & Simon, 1996b), we hypothesize that the masters will present greater brain activation in temporal areas (typically related to long-term memory storage) in the condition of logical chess positions as compared with brain activation in the random positions condition. On the contrary, the frontal and parietal areas (typically related with maintenance and manipulation of information) would not present differences when comparing these two conditions.

Taking the above into account, we posed the following three experimental hypotheses. First, the masters would present a very different brain activation pattern from the novices. Second, in the contrast of structure (chess positions vs. random positions), the masters would display high activation in temporal areas, whereas the there would be no differences in the novices. Third, in the two familiarity contrasts (symbols of normal pieces on a chess board vs. geometric figures on a grey-and-white board), the masters would not present differences in brain activation and the novices would show high brain activation, especially in frontal areas.

Method

Participants

Sixteen healthy volunteers with normal vision signed an informed consent and participated in the experiment. Two of them were chess masters (an 18-year-old grand master with 2550 Elo[1] points and a 20-year-old international master with 2450 Elo points) and twelve were university students who knew how to play chess but who had never participated actively in the game (mean age = 21.4 years, *SD* = 1.4). Initially, 19 novices participated in the experiment but 5 of them were eliminated because they moved their heads more than was permitted in the criterion we had adopted. The ethical rules set by the Sir Peter Mansfield Magnetic Resonance Centre of the University of Nottingham were followed.

Instruments

The experiments were carried out in a scanner in the Sir Peter Mansfield Magnetic Resonance Centre in the Nottingham University (United Kingdom). The scanner has a magnetic field of 3 teslas. The stimuli were presented on a screen placed at a distance of 220 cm from the participants, who used prismatic glasses to observe them.

[1] Elo (1978) developed a ranking that was employed from then on by the International Chess Federation. The World Champion has more than 2800 points, grand masters typically have more than 2550 points, and international masters have more than 2400 points. A novice would have approximately 800 points but the International Chess Federation only includes in its lists players with more than 1800 points.

Images of the entire brain were obtained with 22 coronal sections every 136 ms, so that the time lapse between the acquisition of volume 1—the entire brain—and the next volume was 3 s. The images obtained were echoplanar images calibrated at T2*. The size of each section was 64 × 64 voxels (three-dimensional pixels). Each voxel used was 3 × 3 mm in plane and 9 mm thick. At the end of the experiment, higher resolution anatomical images were obtained to present the data.

Procedure

All the blocks of all the conditions had the same structure (see Figure 1). Each block began with a fixation cross that appeared on the screen for 13 s, followed by a reference stimulus for 3 s. After a 5-s delay, a trial stimulus was presented for 3 s and the participants had to decide whether or not the trial stimulus was identical to the reference stimulus. They pressed the right key for "yes" and the left one for "no." The participants had to respond within 3 s after the presentation of the trial stimulus.

There were four conditions: "chess position," "random chess," "position scene," and "random scene" (see Figure 2). In the chess position, the stimuli consisted of the right half of a chess board (4 × 8 squares) with black and white chess pieces in a logical position of a chess game. In the random chess condition, the chess pieces were distributed randomly on the board. There were 10 pieces (5 white and 5 black) in all the positions and in all the conditions. The stimuli in the position- and random-scene conditions were made up of a grey-and-white background of an irregular design of rectangles with the same dimension as the chess board in the previous conditions and different types of black and white geometric figures that corresponded to chess pieces (a cross represented the king, a hexagon the queen, a square the rook, a rectangular triangle the bishop, an L-shaped figure the knight, and a rectangle the pawn). The positions were generated as follows. A logical chess position was generated by the first author (a chess-player with 2200 Elo points) with 5 white and 5 black pieces, always using 3 pawns, a king, and the fifth piece was either a queen, a rook, a bishop, or a knight. In the random conditions, the pieces corresponding to the same position were replaced randomly on different squares. In the conditions containing "scenes," other chess positions were generated, and subsequently the pieces were replaced by the corresponding geometric figures and lastly, the chess board was replaced by the grey-and-white background already described.

In 50% of the presentations, the trial stimulus was identical to the reference stimulus. When it did not coincide with the reference stimulus, the trial stimulus only differed in two pieces or figures that were on other squares. In the conditions of logical chess positions, changing the position of the pieces corresponded to legal moves, in the case of the random conditions, the change corresponded to illegal moves.

Seventy-two blocks (18 for each condition) were presented in groups of 4 blocks, in which each condition was presented once. The order of the conditions within the block was designated randomly. A new stimulus was used in each block.

Data Analysis

Data were processed with Statistical Parametric Mapping (SPM99; Friston et al., 1995). Once the coordinates were obtained in the Montreal Neurological Institute (MNI; Coscoso, Kollokian, Kwan & Evans, 1997) system, they were translated into the Talairach (see Talairach & Tournoux, 1988) system, and the Brodmann areas were obtained by means of the Talairach Daemon (Lancaster, Summerln, Rainey, Freitas, & Fox, 1997) program.

With regard to the behavioral results, given the low number of chess-players, we only present the descriptive statistics. In terms of results of brain imaging, the statistical model employed was the "autobox" function in convolution with the hemodynamic response function. Three contrasts

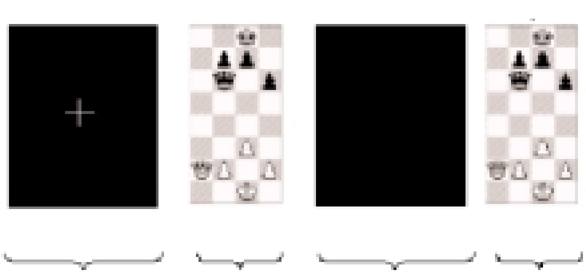

Figure 1. Structure of the block. (See details in text).

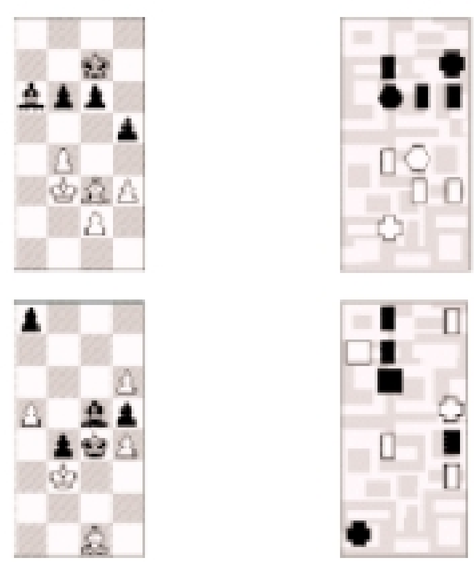

Figure 2. Stimuli employed in the experiment. Upper left = chess position; upper right = position scene; lower left = random chess; lower right = random scene.

were planned in the novice group and for each of the masters: (a) structure contrast: chess position > random chess[2]; (b) familiarity contrast 1: chess position > scene position; and (c) familiarity contrast 2: random chess > random scene. Parametric statistical maps (SPM) of *t* values were obtained after correcting for multiple comparisons. Only the groups of more than 5 voxels are reported.

Results

On the average, all the subjects performed much better than would be expected if their behavior had been random. The grand master responded correctly on more than 90% of the trials in all conditions, the international master responded correctly between 75 and 90% of the attempts.

Table1
Coordinates of the Areas of Greater Local Brain Activation of all the Contrasts in Novice Players

Contrast	Voxels	Hemisphere	Area	AB	*t* value	*Z* value	Talairach coordinates		
							x	*y*	*z*
Chess position >	8	L	Temporal gyrus	38	4.89	4.88	–47	17	–8
	21	L	Inferior frontal gyrus	44	5.05	5.04	–56	15	13
Random chess	6	L	Middle frontal gyrus	46	4.72	4.72	–44	30	20
	6	L	Inferior frontal gyrus	47	4.69	4.69	–47	32	–2
	12	L	Cuneus	19	4.97	4.96	–3	–77	37
	15	R	Precuneus	7	4.67	4.67	9	–68	34
	7	R	Inferior parietal lobe	40	4.68	4.67	62	–33	29
		R	Inferior parietal lobe	40	4.5	4.49	59	–40	24
	276	R	Posterior cingulate cortex	29	5.73	5.72	3	–46	8
		L/R	Posterior cingulate cortex	23	5.14	5.13	0	–22	29
		L/R	Posterior cingulate cortex	29	5.13	5.12	0	–46	19
	1233	L/R	Anterior cingulate cortex	32	6.29	6.28	0	33	26
		R	Superior frontal gyrus	8	6.1	6.09	6	35	53
		L	Superior frontal gyrus	8	5.74	5.73	–3	17	52
Chess position >	35	L	Ínsula	13	5.11	5.1	–42	3	–5
Position scene		L	Superior temporal gyrus	22	5.01	5.01	–53	0	0
	68	L	Middle frontal gyrus	10	5.98	5.97	–24	62	8
		L	Superior frontal gyrus	10	5.19	5.19	–24	52	0
	59	R	Middle frontal gyrus	6	4.88	4.87	27	20	54
		R	Middle frontal gyrus	6	4.83	4.82	24	5	49
		R	Middle frontal gyrus	6	4.76	4.76	36	0	58
	6	L	Middle frontal gyrus	46	4.71	4.7	–48	33	20
	64	L	Inferior frontal gyrus	45	5.42	5.41	–53	21	7
	167	R	Cerebellum		6.19	6.18	30	–59	–12
		R	Cerebellum		5.18	5.18	36	–45	–20
		R	Cerebellum		4.59	4.59	45	–63	–27
	30	L	Cerebellum		5.57	5.56	–42	–51	–28
	117	R	Thalamus		5.52	5.51	6	–23	4
		R	Amygdala		5.44	5.43	18	–9	–10
		R	Brainstem		4.84	4.83	12	–21	–4
Random chess >	6	L	Posterior cingulate cortex	31	4.91	4.91	–24	–66	17
Random scene									

Note. Voxels = number of voxels activated in the group (when the number of voxels is not presented, it means that this area belongs to the same group as the previous row). AB = Brodmann's area; Talairach coordinates: *x* = negative numbers correspond to the left hemisphere and positive numbers to the right hemisphere; *y* = positive numbers correspond to areas in front of the anterior commissure and negative numbers correspond to areas behind the commissure; *z* = positive numbers correspond to areas above the anterior commissure and negative numbers to areas below it.

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[2] In a contrast, the brain activation obtained in a certain condition is subtracted from that obtained in another condition. The nomenclature "x > y" means that the voxels presented were activated with (statistically) significantly greater intensity in the condition x than in the condition y.

Table 1 displays the brain activation areas in the three contrasts proposed. Only the data of the novices are presented because the two masters did not present differences in brain activation in any of the contrasts.

In the novice players, the chess position > random chess contrast presented a very limited activation pattern in a small group of temporal areas and in a somewhat larger group of frontal areas. The chess position > position scene contrast presented a pattern of very extensive brain activation in posterior areas of both hemispheres (i.e., the posterior cingulate cortex, precuneus, temporal areas, and cerebellum), but mainly in frontal areas (middle and superior frontal gyri and anterior cingulate cortex). In the random chess > random scene contrast, the novices presented an activation pattern of only 6 voxels in the left posterior cingulate cortex. Figure 3 shows a model brain with the brain activations of the novices in the contrast that presented more activation, that is, the chess position > position scene.

As the masters did not present any brain activation in any of the three contrasts, it could be argued that the lack of a significant effect was due to a technical flaw during the experiment or to a lack of sensitivity of the scanner during their participation. That is, perhaps the reason for the lack of a significant effect was not that the activations were similar in the conditions compared but rather because the scanner did not detect any activation. In order to discard this possibility occurring with the masters, we performed an analysis in which we compared their brain activation during the periods in which the reference stimulus was presented and the delay when the fixation cross was presented. The presentation period of the trial stimulus was not taken into account so as to discard activation in the motor areas corresponding to finger movement when pressing the key.

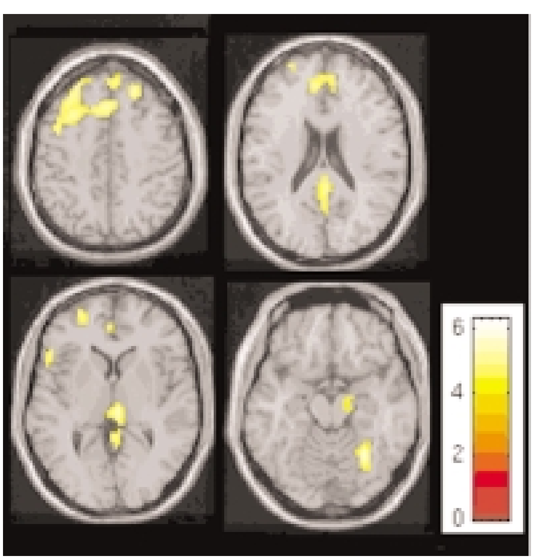

Figure 3. Novice players. Contrast Chess position > position scene. Four axial images from top to bottom of the brain, showing brain activation.

Figures 4 and 5 show the activated brain areas in this contrast. The fact that the brain activation pattern was significant in the two masters confirms that their lack of activation in the three structure and familiarity contrasts was not due to a technical error or to a lack of sensitivity of the scanner, but to the fact that their brain activations were similar in the conditions compared. Thus, the results obtained allow us to draw conclusions regarding the hypotheses we had proposed. The analysis of the areas that appear activated in Figures 4 and 5 is of no interest to the experimental hypotheses because all the conditions were grouped together.

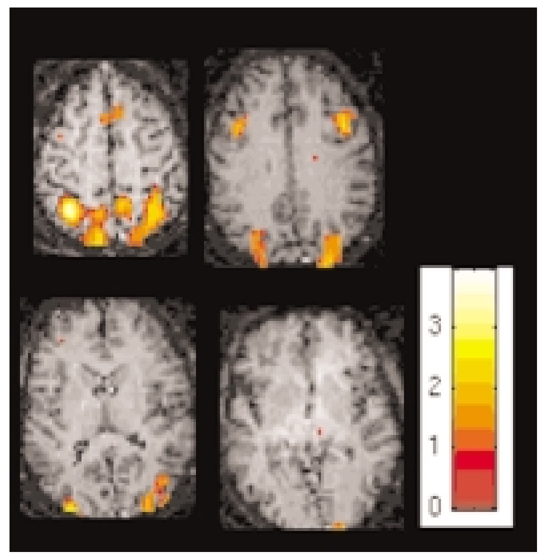

Figure 4. Contrast trial stimulus plus delay > fixation cross (grand master). Four axial images from top to bottom of the brain, showing brain activation.

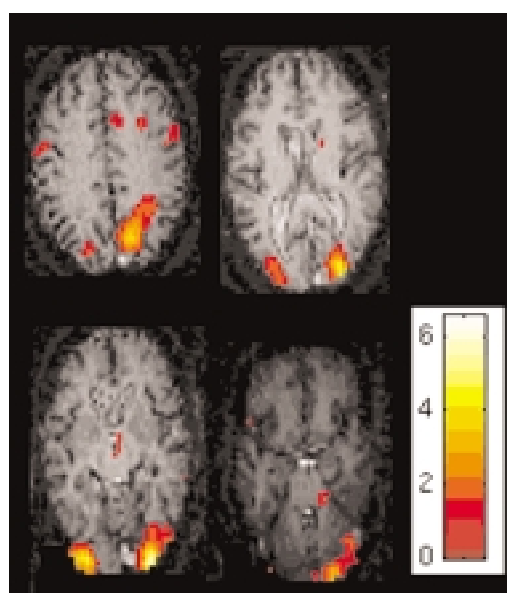

Figure 5. Contrast trial stimulus plus delay > fixation cross (international master). Four axial images from top to bottom of the brain, showing brain activation.

Discussion

Three important results were revealed by this experiment. First, neither of the masters presented differences in the relevant contrasts. Second, the lack of significant differences was not due to a technical problem or to lack of sensitivity of the scanner. Third, the novices showed a very broad activation pattern in the chess position > position scene contrast and very limited activation in the other two contrasts.

With regard to the hypotheses proposed, the results of the experiment support the hypothesis that stated that the masters would present a different brain activation pattern from the novices. The hypothesis stating that the masters would not present differences in brain activation in the familiarity contrasts and that the novices would present important differences in brain activation in these contrasts (especially in frontal areas) received some support, as three of the four expected results were produced. Both the results of the masters in the familiarity contrasts had been predicted (that is, lack of differences between the compared conditions). We also correctly predicted the extensive activation in the novices in the chess position > position scene contrast. However, the novices' low activation in the random chess > random scene contrast was unexpected.

Lastly, the hypothesis about the structure contrast—activation in temporal areas in the masters and lack of differences in the novices—was refuted by the results obtained because we found no differences in brain activation in the masters and we did find differences in the novices.

We shall try to provide a plausible explanation of our results. In the case of the masters, the lack of significant differences in the familiarity contrasts was expected, as previous experiments showed that advanced chess-players are not affected by the change of a symbol to represent the pieces (Chase & Simon, 1973b; Saariluoma & Kalakoski, 1997). The two masters commented to the experimenter that they easily memorized the correspondence of the geometric figures with chess pieces, and this was facilitated by the similarity between the figures and the pieces, and that during the experiment, they perceived the figures as if they were chess pieces.

With regard to the structure contrast, on the basis of the extensive literature that reports clear differences in masters in the reconstruction of logical and random positions (see Gobet, De Voogt, & Retschitzki, 2004 for a bibliographic review), we predicted a difference in the brain activation of our masters. However, this did not occur. A possible explanation is that the simplicity of the task led the masters to perform the same processes for both stimuli. The differences found in the literature refer to a recall task (the reconstruction of the position of each piece in a position presented during a 2- to 15-s period), and our task was a recognition task.

With regard to the novices, we had hypothesized that there would be a familiarity effect (which partially occurred) and that there would be no structure effect, which did, in fact, occur. A possible explanation is that, in the conditions using chess pieces and the chess board, the visual representation of the reference stimulus in posterior areas of the brain may have been generated in a different place from the representation in the conditions using geometric figures (this would explain the activation in posterior areas in the chess position > position scene and random chess > random scene contrasts). It is also possible that during the delay period, in both the conditions with geometric figures, the novices may have performed a similar type of processing (with the differences in structure having no effect, contrary to our prediction), which could be a visual review. In contrast, in the two conditions with chess pieces, the type of processing would have been different. In the condition with a logical position, the novices would have performed some kind of verbal processing (for example, reciting the name of the pieces) that would require more activation in modulation areas such as the frontal cortex. On the contrary, in the random position, the novices, not recognizing a logical position, would continue to perform the same type of processing as in the conditions with geometric figures. This would explain the existence of brain activation in the frontal areas in the chess position > random chess and chess position > position scene contrasts. In the future, an experiment using the event-related fMRI technique, in which one can obtain precisely the activation in each period of the block, would allow us establish whether or not our explanation is adequate.

Lastly, in accordance with previous studies in brain imaging with chess-players (Amizdic et al., 2001; Atherton et al., 2003; Nichelli et al., 1994; Onofrj et al., 1995), our study revealed brain activation in frontal areas of the novices but not in the masters. This may reflect the fact that, for the novices, the chess symbols generated an additional demand in the process of maintaining the information of the reference stimulus and, therefore, more activation in frontal areas. However, the masters' familiarity with the chess symbols resulted in their not generating any additional processing demand.

The results obtained in this experiment confirm some of the hypotheses proposed in the scientific literature of psychology. The difference between expert and novice players is based mainly on the creation of a long-term memory with typical configurations (Gobet & Simon, 1996). The experts are very skilled at using different symbols quickly, as long as the structure of the stimulus is logical (Chase & Simon, 1973b; Saariluoma & Kalakoski, 1997). In addition, our experiment contributes new information. First, it provides data about the brain areas involved in the acquisition of expert knowledge. For example, in contrast to the masters, the novices require high activation in frontal areas in the chess position condition, which suggests a switch in the masters' type of processing, from anterior to posterior areas of the brain.

The paradigm of comparing experts and novices has not only provided relevant data about the acquisition of levels of excellence (see Charness, Krampe & Mayr, 1996;

Cranberg & Albert, 1988; and Ericsson, Krampe & Tesch-Romer, 1993, for theories of acquisition of excellence), it has also contributed to the generation of theories on cognitive processes such as perception (Chase & Simon, 1973b), memory (Chase & Simon, 1973b; Ericsson & Kintsch, 1995; Gobet & Simon, 1996), and thinking (De Groot, 1946/1978; Newell & Simon, 1972). We believe its use in experiments of brain imaging will contribute enormously to the knowledge of the brain systems involved in the above-mentioned cognitive processes and, especially, in the changes that occur in these processes in the course of which a novice player becomes an expert.

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